Risks Posed by Brines Containing Dissolved CO_2

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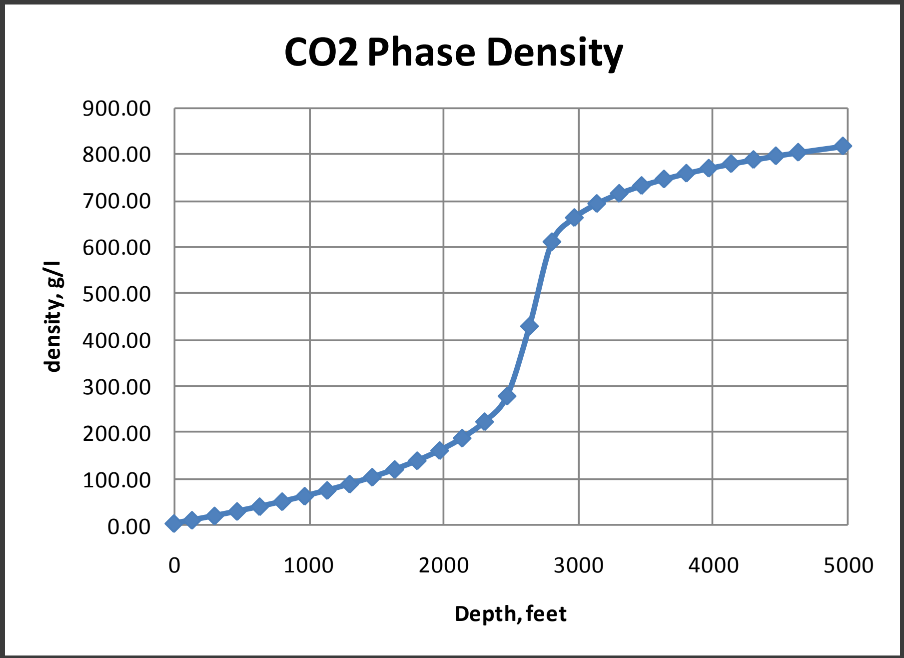
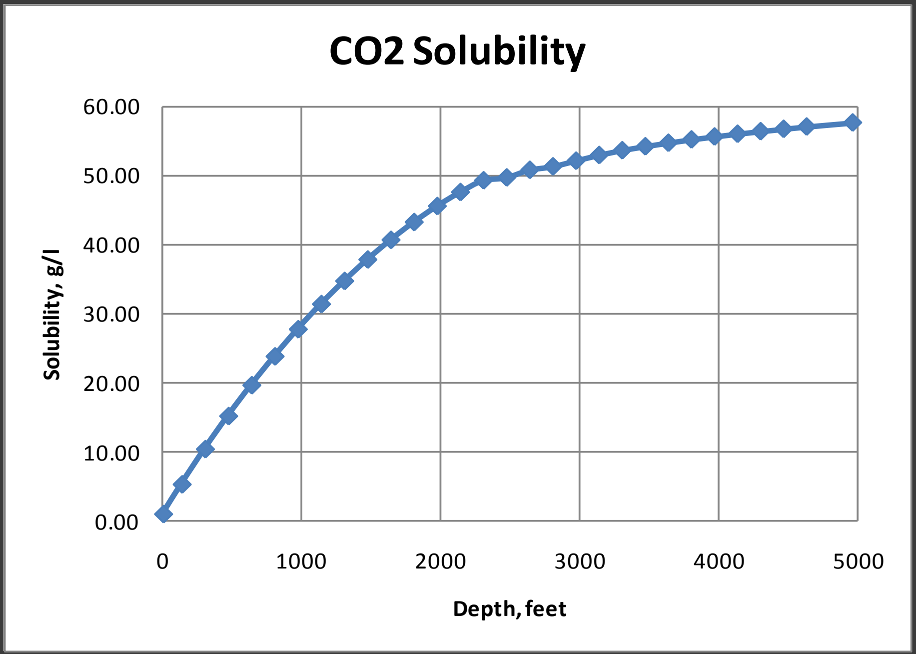
EPA- Science to Achieve Results (STAR) project (3 year)

- Ron Falta (PI): *multiphase flow, subsurface remediation, modeling*
- Sally Benson (Co-PI): *geologic CO_2 sequestration, laboratory experiments of CO_2 relative permeability*
- Larry Murdoch (Co-PI): *hydrogeology, subsurface remediation, modeling*
- Graduate Students: Miles Atkinson, Kirk Ellison, Chris Patterson, Catherine Ruprecht at Clemson; MS student at Stanford
- Barbara Klieforth: EPA Project Officer

CO_2 Density and Solubility with Depth

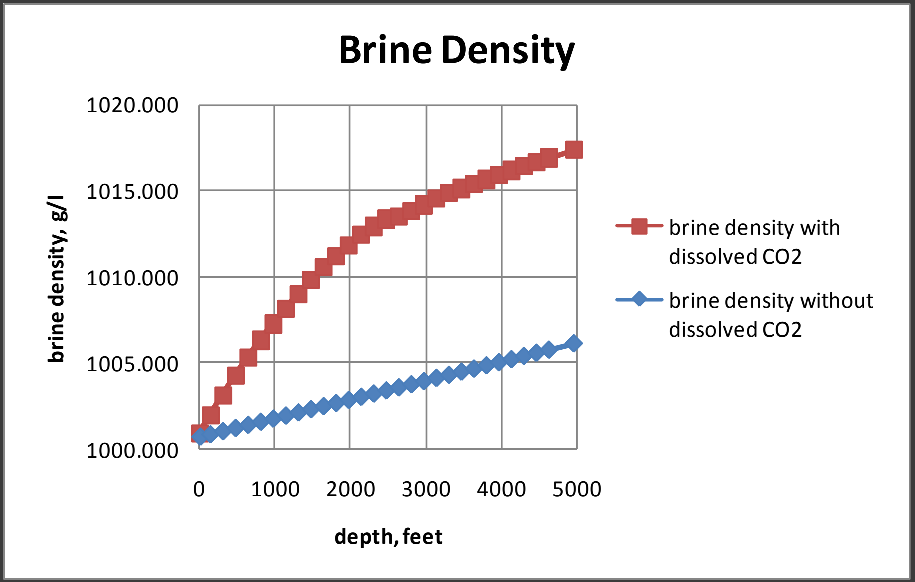




Calculated using the Lawrence Berkeley Lab TOUGH2-ECO2N code assuming 35º C and 10,000 mg/l NaCl

The high CO_2 solubility is significant

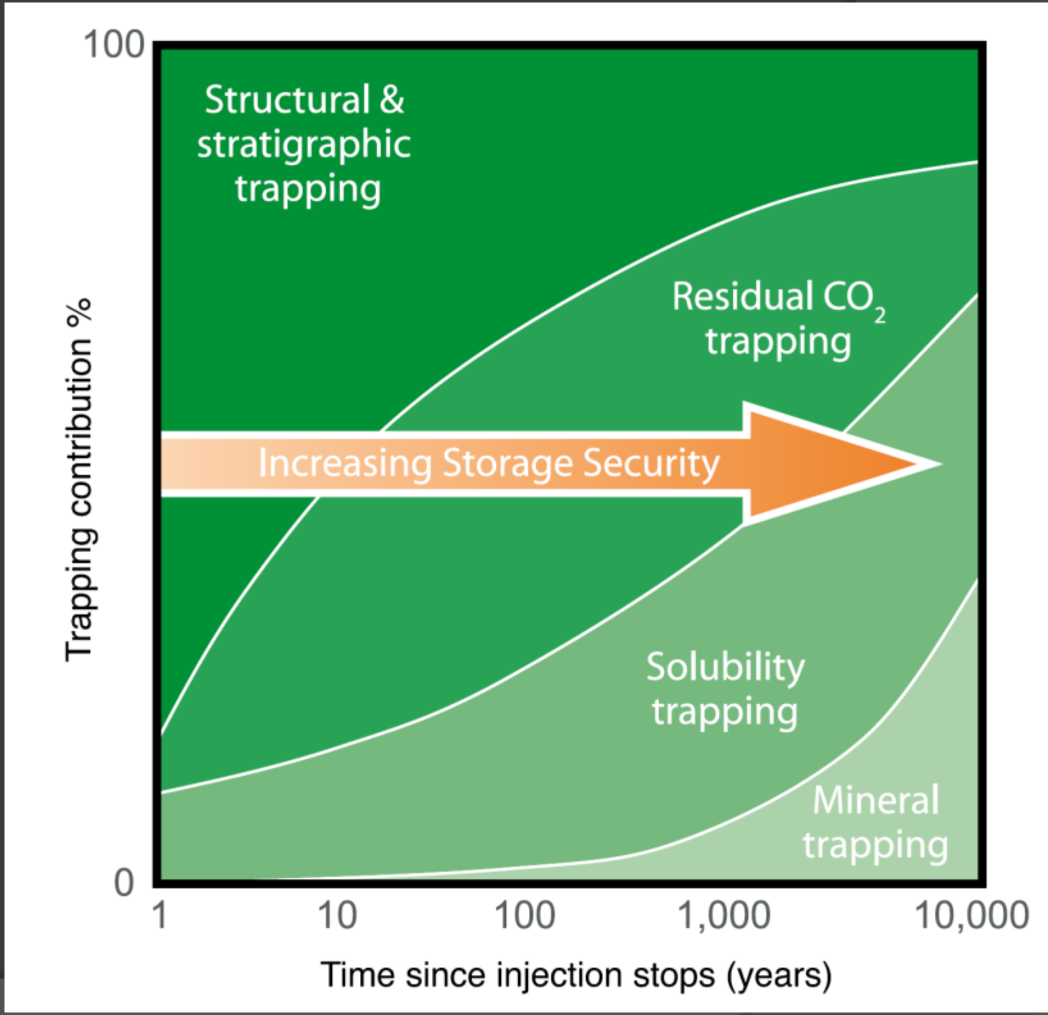
- At 3000 ft depth, we get ~50 g/l (50 times more CO_2 than beer!)
- At a CO_2 phase saturation of 7%, the amount of CO_2 that is dissolved equals the amount in the supercritical CO_2 phase
- When CO_2 dissolves, the aqueous phase becomes more dense (about 1% here)



Calculated using TOUGH2-ECO2N

Geologic CO_2 Storage Security

- Stratigraphic trapping – supercritical CO_2 trapped by confining layers
- Residual CO_2 trapping – supercritical CO_2 is locally trapped by capillary forces
- Solubility trapping – CO_2 dissolves in pore water (up to 60 g/l)
- Mineral trapping – CO_2 reacts to form solid minerals (carbonates)



IPCC, 2005

The Dissolved CO_2 is Secure -- Or Is It?

- Density increase favors downward flow of CO_2 saturated brine
- Upward flow would require a caprock defect, and an upward hydraulic gradient
- **However, if a saturated CO_2 brine moved upward, the CO_2 would come out of solution (exsolve), leading to a potentially mobile gas phase**

Darcy's Law for buoyancy flow

$$V = -\frac{k}{\mu}(\bar{\rho} - \rho_\infty)g$$

Darcy's Law for groundwater flow

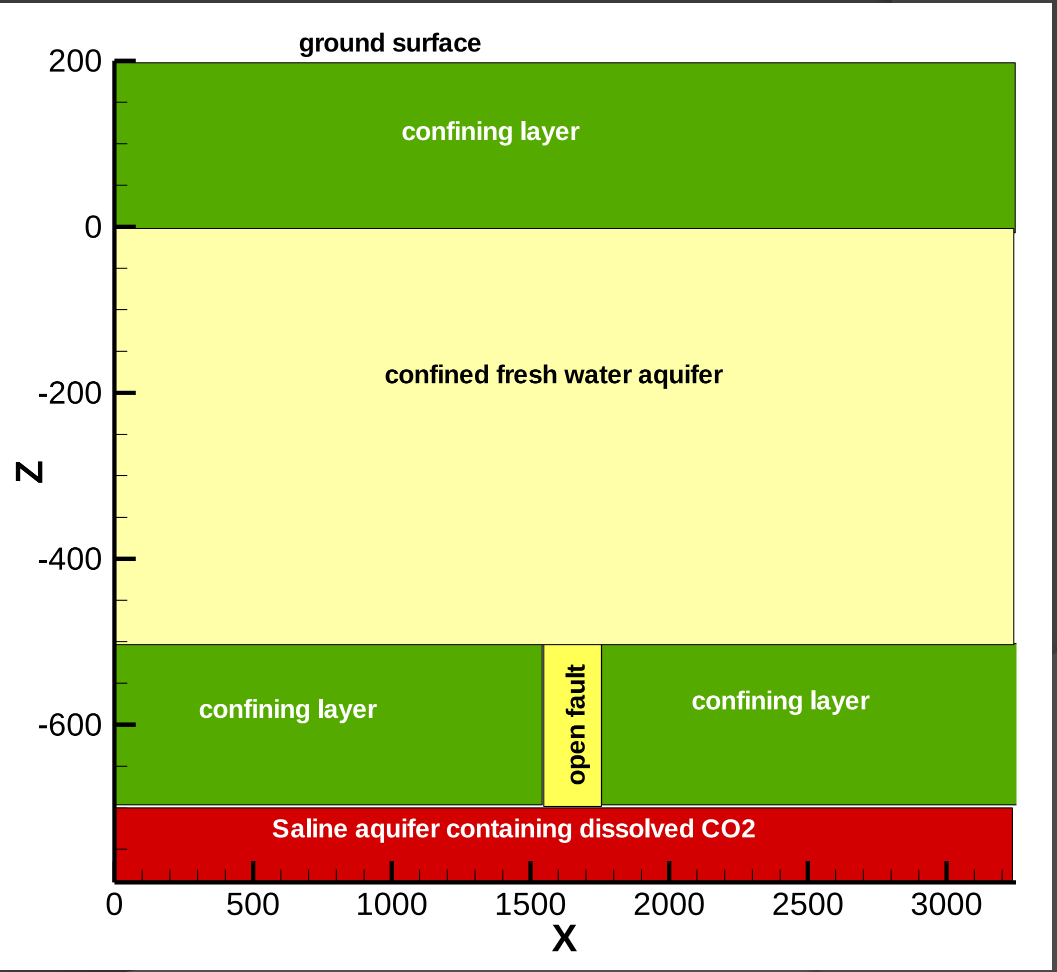
$$V = -K\frac{\partial h}{\partial z} = -\frac{k\rho_\infty g}{\mu}\frac{\partial h}{\partial z}$$

Critical upward gradient to mobilize CO_2 saturated brine

$$\left|\frac{\partial h}{\partial z}\right| = \frac{(\bar{\rho} - \rho_\infty)}{\rho_\infty}$$

TOUGH2-ECO2N simulation: CO_2 saturated brine moves up an open fault to a shallower aquifer

- Confined saline formation contains 50.7 g/l CO_2
- Connected to fresh water aquifer by fault, $k=10^{-11}$ m^2
- System initially in static equilibrium
- Reduce hydraulic head at top of upper aquifer by 30 m.



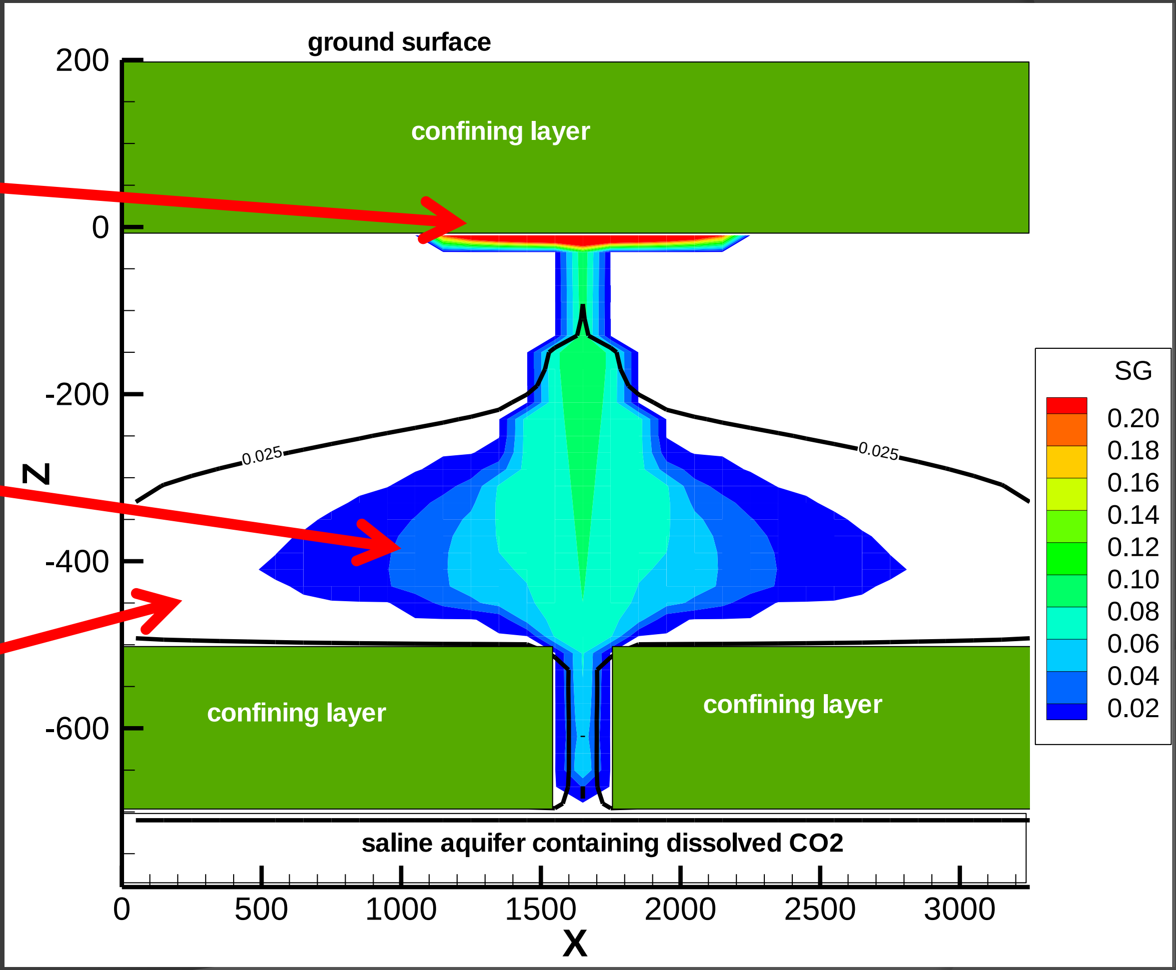
Vertical exaggeration of 3:1

CO_2 gas saturation after 100 years, low gas residual trapping (S_{gr} = 5%)

Mobile gas phase moves to top of aquifer

Large zone of trapped gas phase CO_2 is formed

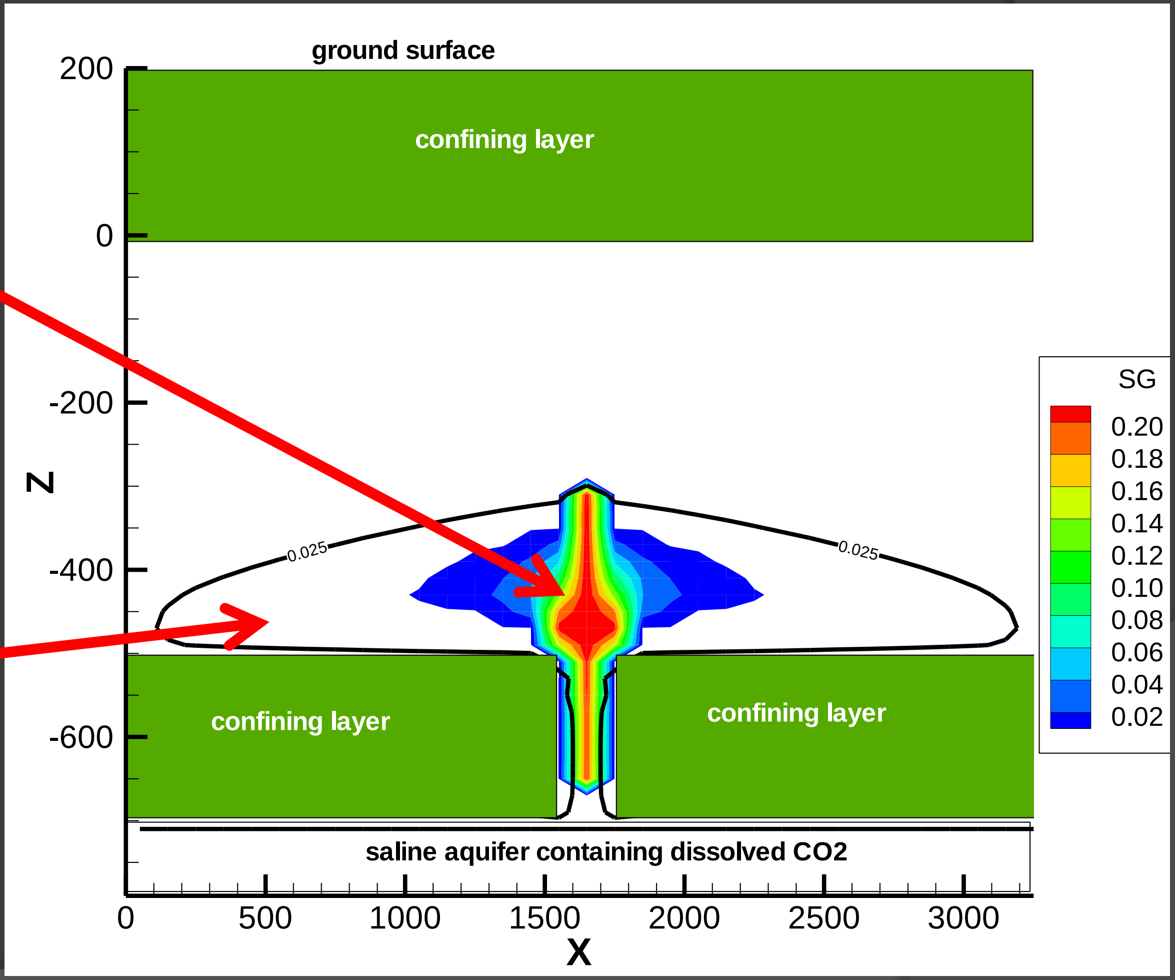
Dense brine with dissolved CO_2 moves away from fault laterally



CO_2 gas saturation after 100 years, high gas residual trapping (S_{gr} = 20%)

Small zone of trapped gas phase CO_2 is formed. Gas never achieves high mobility

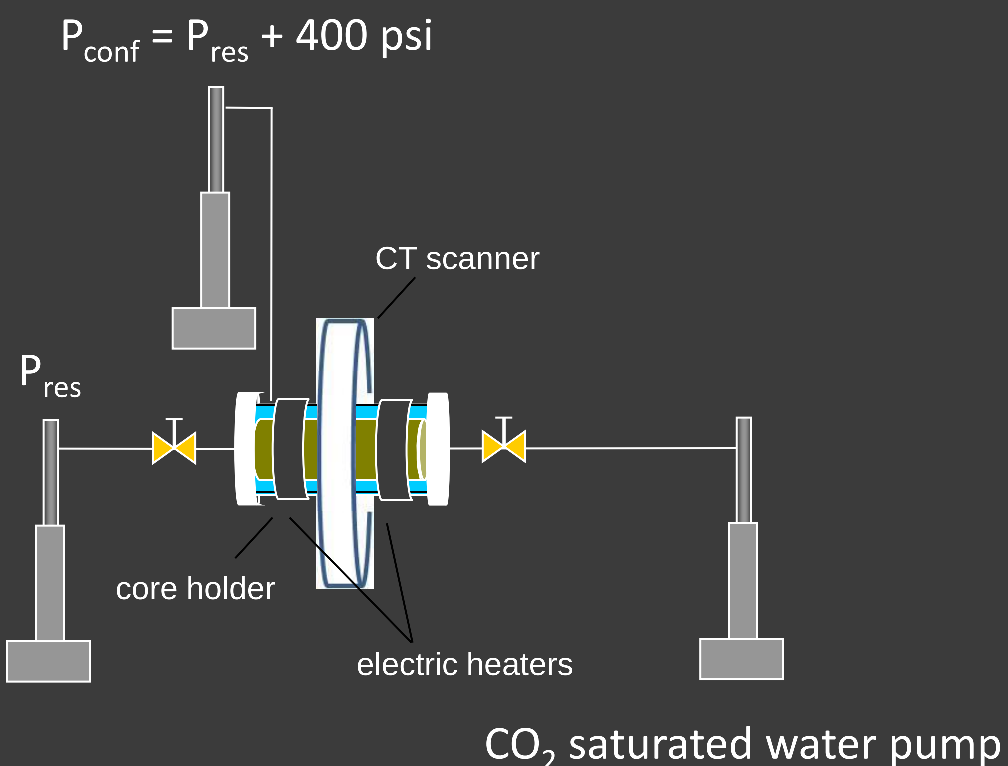
Dense brine with dissolved CO_2 moves away from fault laterally



Project Objectives

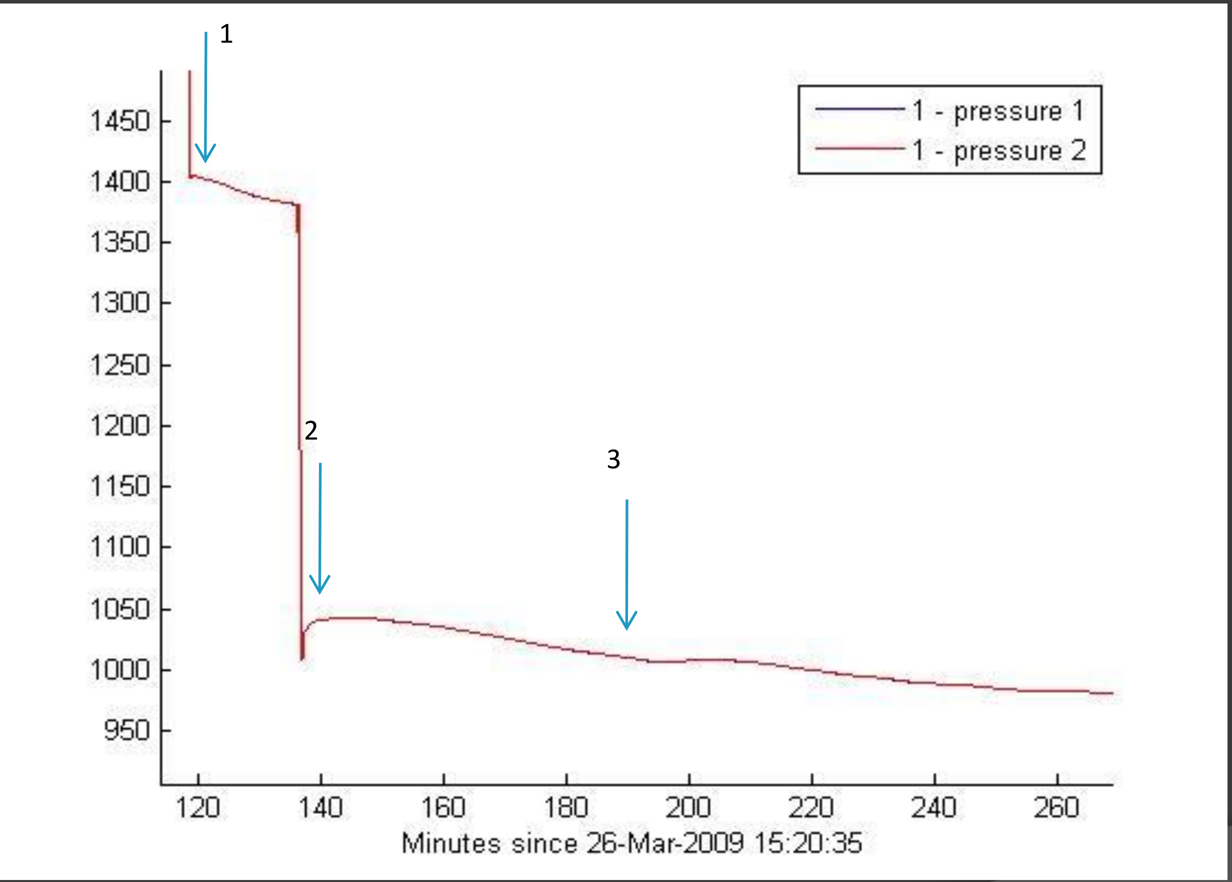
- Develop pore-level understanding of the gas exsolution process (experimental, numerical)
- Determine mobility of exsolved CO_2 (experimental)
- Establish relative permeability characteristics of exsolved CO_2 (experimental, numerical)
- Evaluate local and regional scale hydrogeologic characteristics that could lead to unwanted dissolved CO_2 transport (numerical)
- Evaluate alternative CO_2 disposal schemes for reducing risk
- Determine what methods of remediation would be most effective if CO_2 contamination is detected.

Laboratory experiments – Benson Lab, Stanford

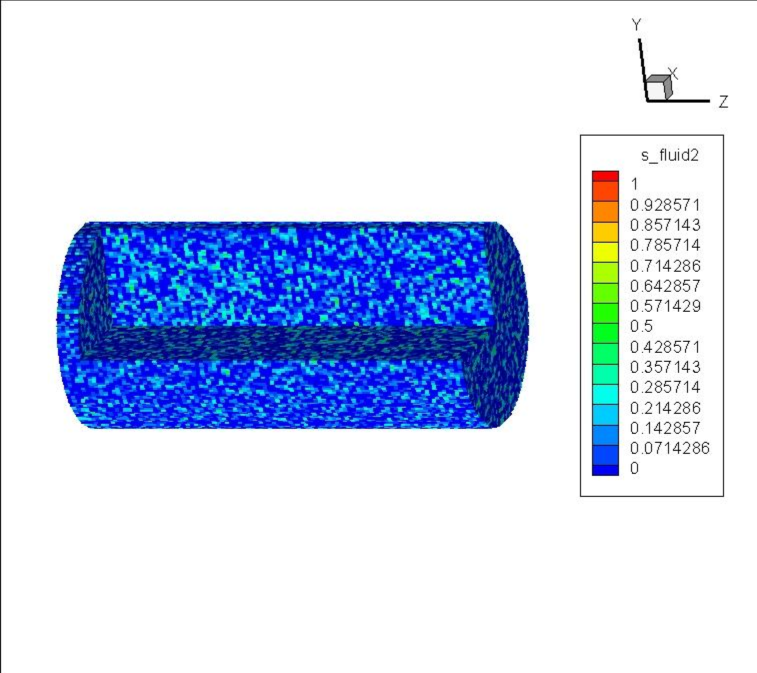


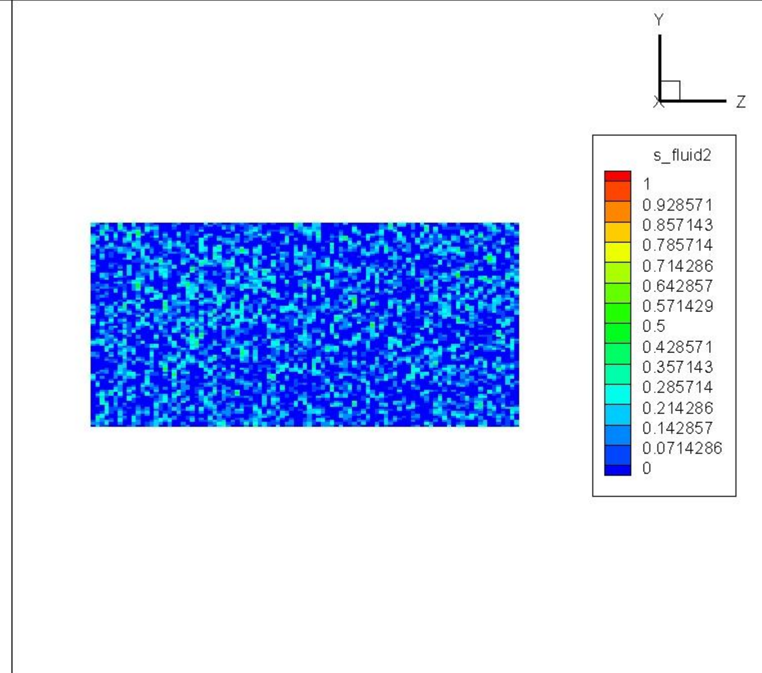
- High pressure core flooding apparatus; can inject CO_2, brine, or both
- Medical X-Ray Computed Tomography (CT) to image gas saturation
- Precision pumps, flow meters, pressure transducers

Initial CO_2 exsolution experiments

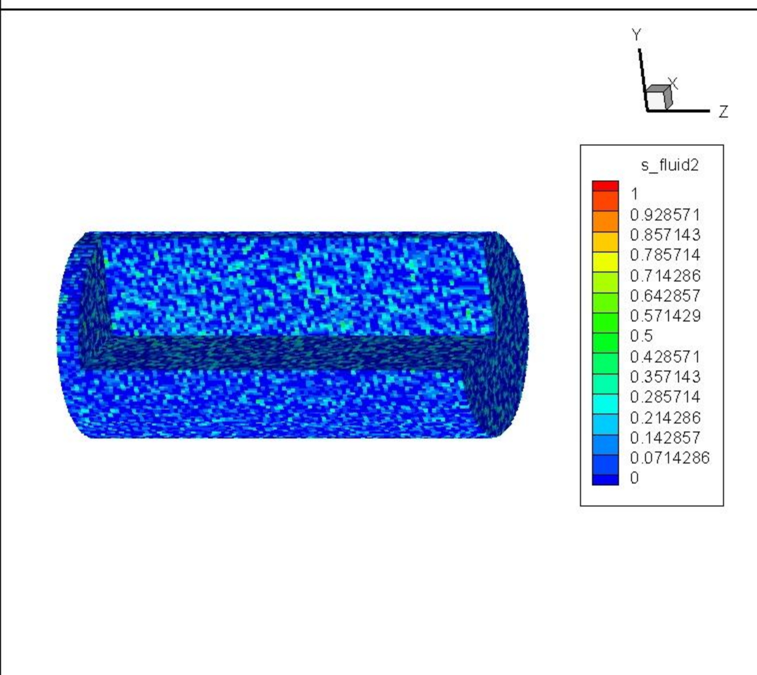


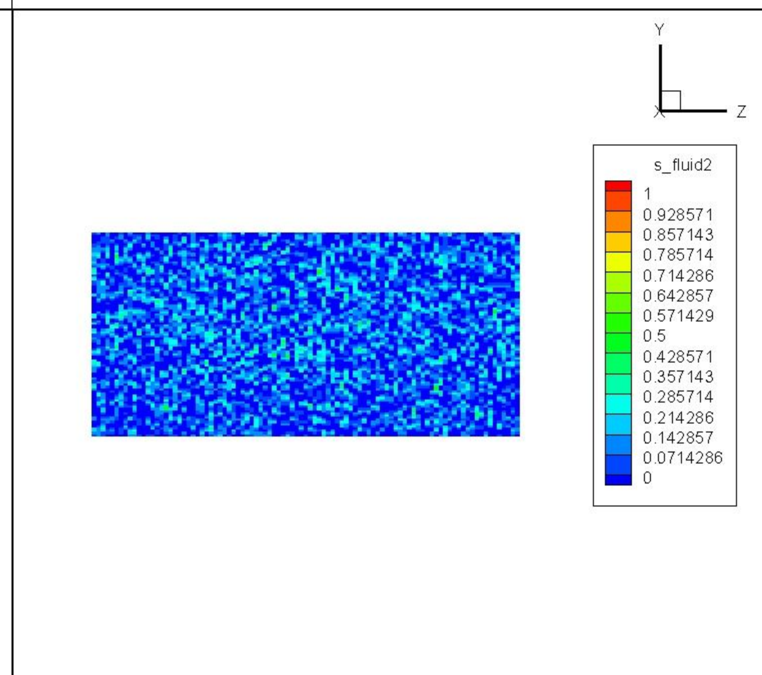
- **Inject CO_2 saturated brine at 1800 psi into brine filled sandstone core**
- **Close valves, then drop core pressure to 1400, and then 1000 psi**





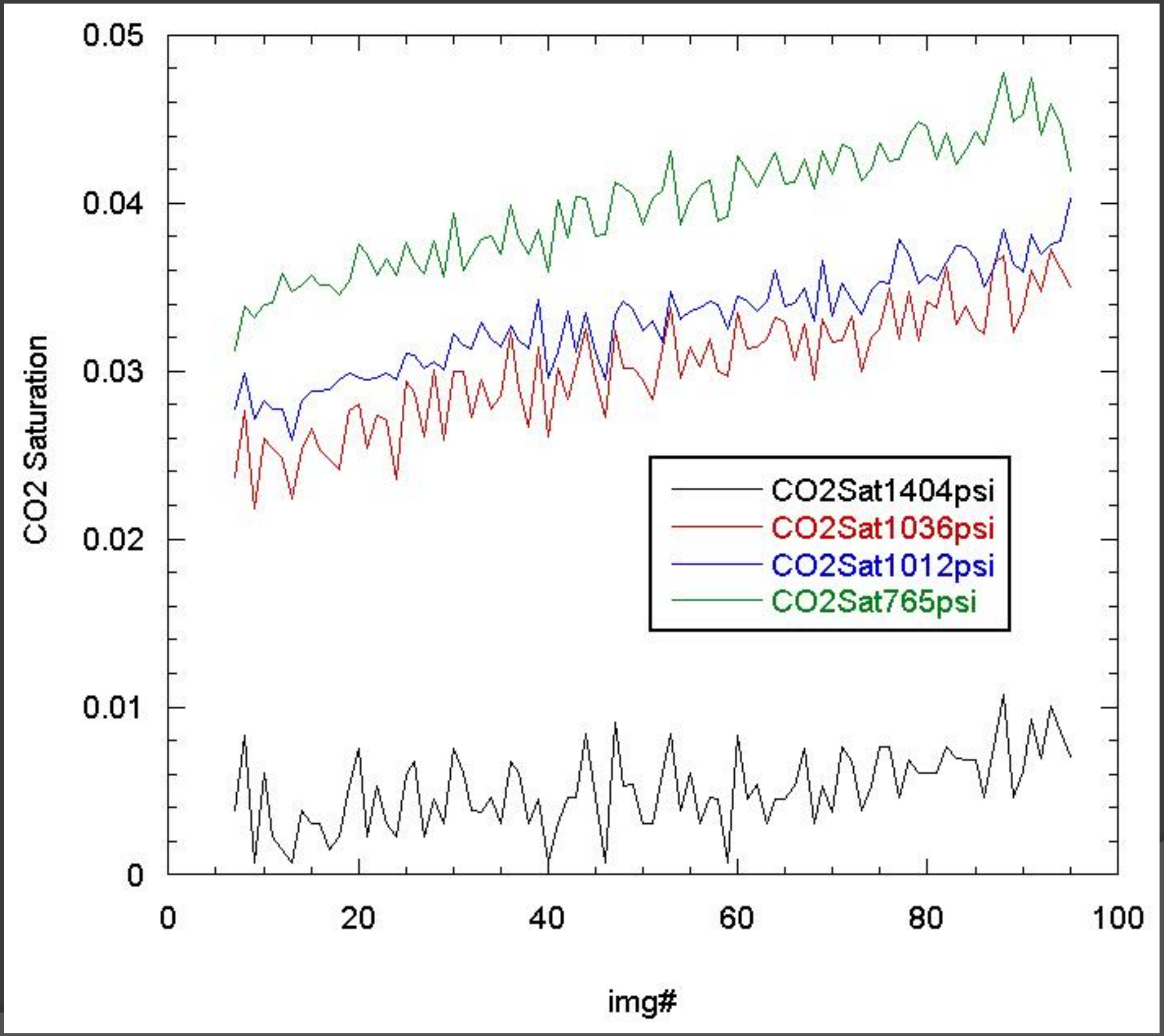
scan 1
1400 psi





scan 2
1036 psi

Initial CO_2 exsolution experiments



Pore-scale simulations

- Use Comsol Multiphysics PDE solver to simulate exsolution and bubble behavior at pore level
- Full fluid mechanics and micro-scale mass transfer

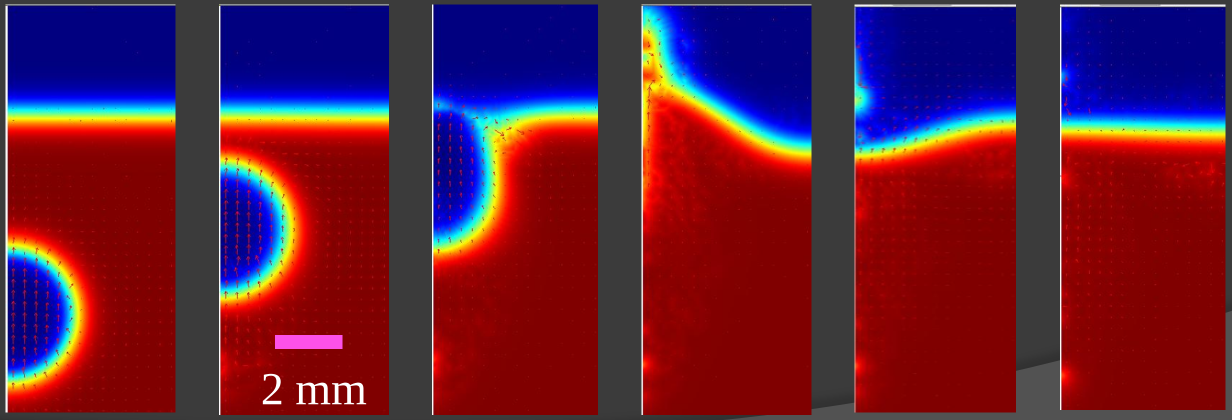
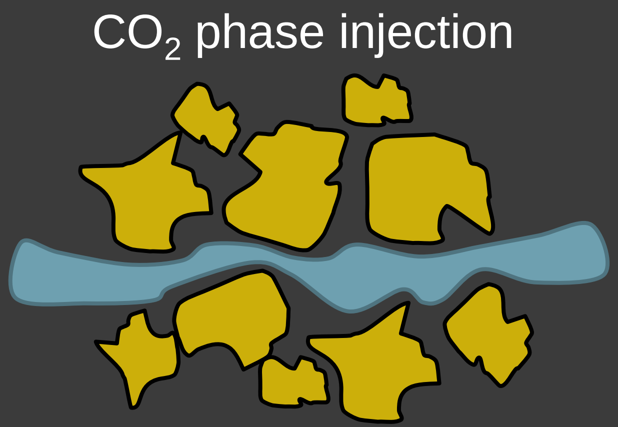
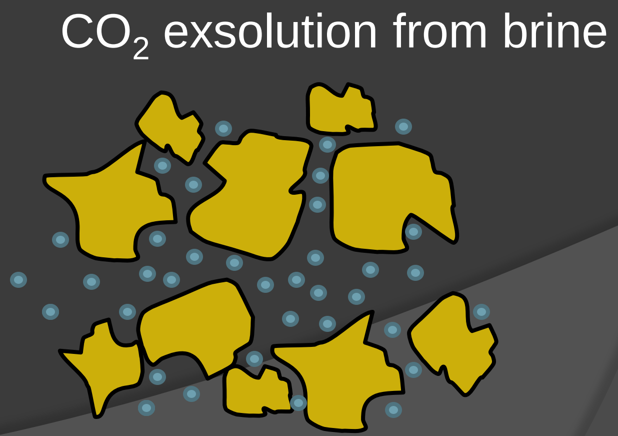


Figure 10. Pore-scale simulation of gravitational coalescence of a rising bubble of NAPL (blue) with a NAPL-water (red) interface using a level-set technique. Proposed simulations would use modified geometry and fluid properties to represent CO_2 in water-filled pores.

CO2 phase relative permeability

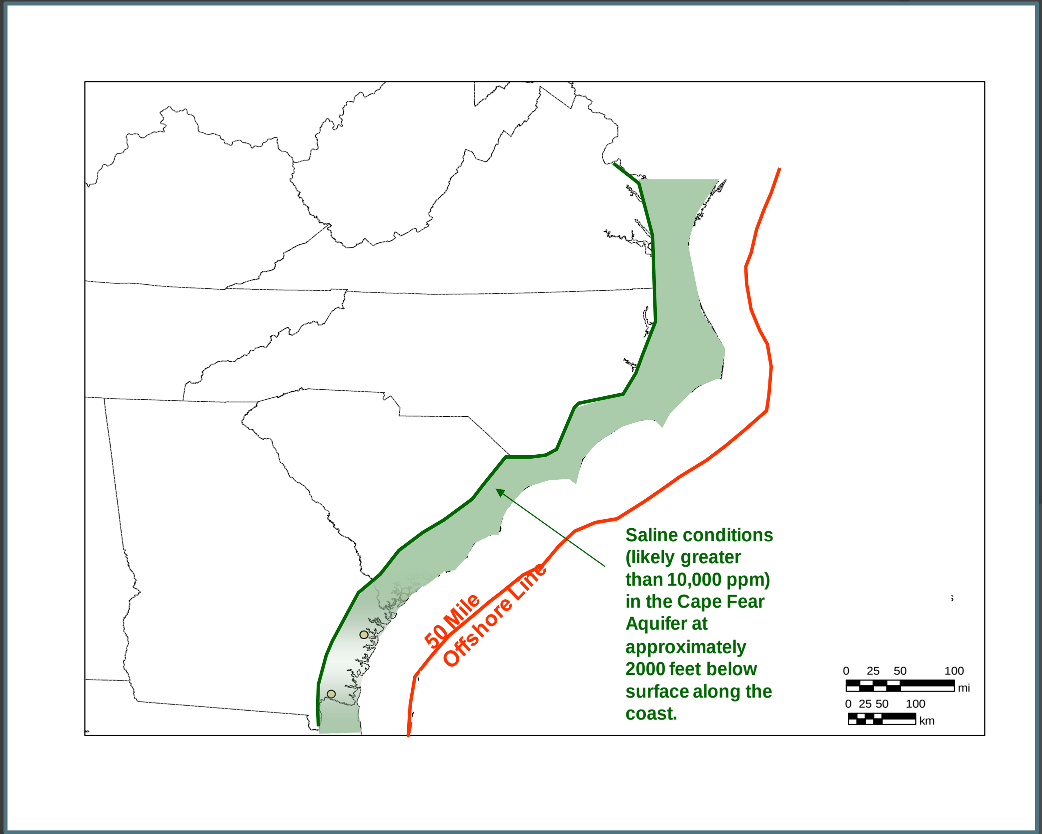
- Evaluate the CO_2 residual saturation (mobility) following exsolution
- Anticipate that behavior may be different from CO_2 phase injection experiments





Regional-scale variable density flow modeling

- Large scale models of current or proposed CO_2 injection sites
- single-phase water flow with brine/ CO_2 density effects
- MODFLOW-SEAWAT or TOUGH2-ECO2N



Multiphase simulation of CO_2 injection

- Multiphase flow simulations with TOUGH2-ECO2N or possibly CMG GEM code
- Study supercritical CO_2 injection followed by dissolution and brine movement
- Use new relative permeability functions/data from experiments
- Also evaluate direct injection of dissolved CO_2

CO_2 remediation designs

- Use the multiphase flow CO_2 simulations as initial conditions
- Use the TOUGH2-ECO2N or CMG GEMS programs
- Evaluate what actions would reduce or eliminate the risk posed by CO_2 that escaped from the original storage formation

Summary

- Three year project that focuses on dissolved CO_2 that comes out of solution upon depressurization
- Laboratory, pore-scale and field scale modeling
- Quantification of exsolved CO_2 mobility and relative permeability
- Development of strategies for reducing risk and remediation